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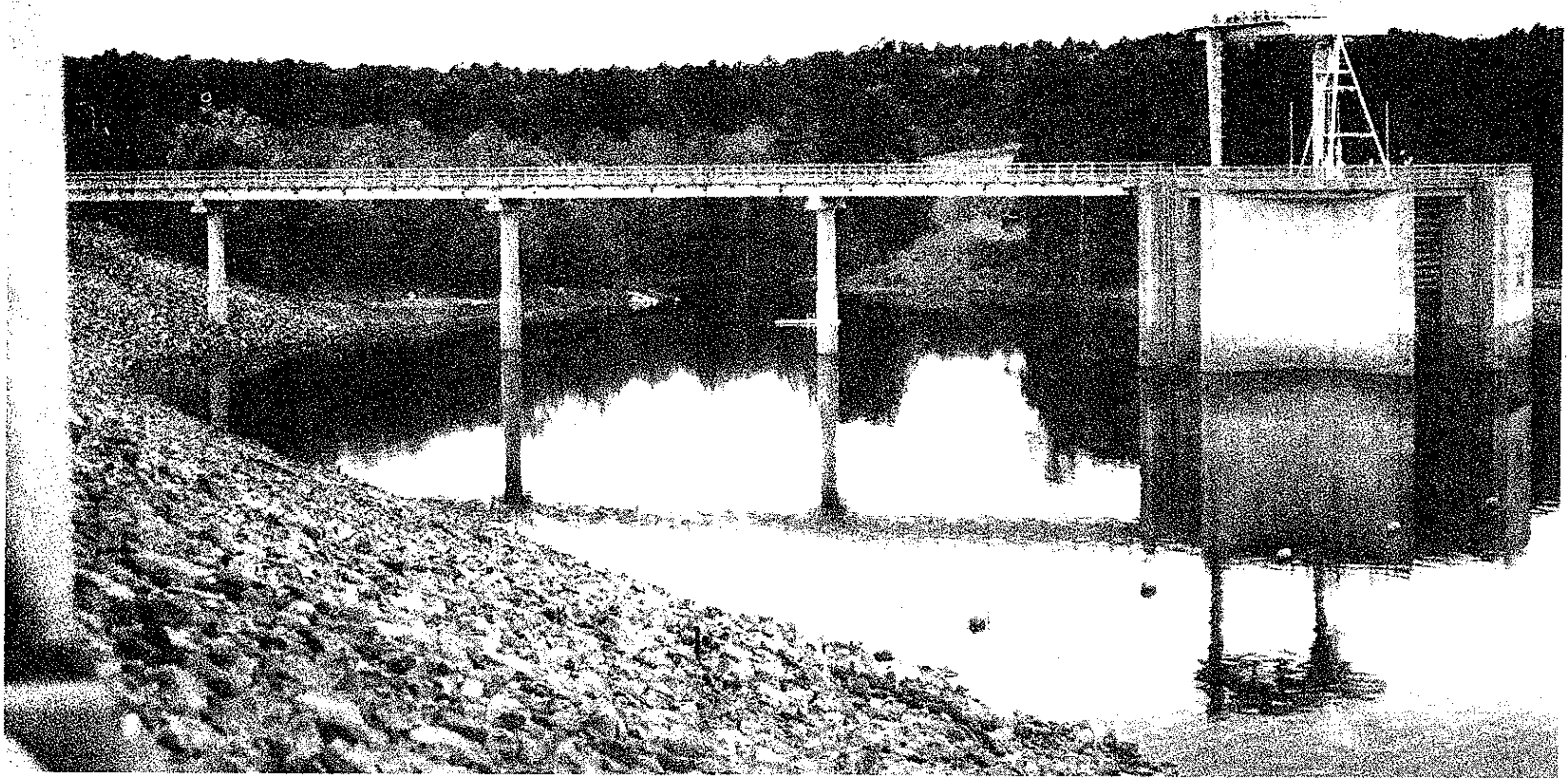

The Corps of Engineers operates reservoir projects to meet downstream environmental quality objectives consistent with authorized project purposes. The Environmental and Water Quality Operational Studies (EWQOS) Work Unit IIB, Reservoir Releases, is designed to provide a better understanding of the influence of reservoir releases on the tailwater ecosystem. This work unit is a cooperative research effort with U.S. Fish and Wildlife Service's National Reservoir Research Program, Fayetteville, Arkansas, and involves studies to determine the effects of specific operational procedures on tailwater ecology. The guidance produced by this work unit will facilitate operation of outlet structures (such as the DeGray Lake, Arkansas, water quality tower shown above) to maintain or enhance the tailwater environment. An overview of the work unit findings to date are given in the following article.

RESERVOIR RELEASES: AN OVERVIEW

*John M. Nestler**

Chemical and physical conditions are altered downstream from reservoir projects. The aquatic biota of tailwater ecosystems respond to the altered conditions by changes in composition and abundance. Present knowledge of project impacts on the tailwater ecosystem is incomplete and environmental requirements of many tailwater biota are inadequately documented.

Work Unit IIB was initiated in 1978 as a comprehensive research effort to describe the impacts of reservoir project operation on the tailwater ecosystem. Effects of reservoir releases were described during a 2-year (1979-1980) monitoring effort of water quality, macrobenthos, and fish at seven sites. These reservoirs varied greatly in project purpose, release depth, and location (Table 1) and are representative of many CE reservoirs throughout the United States. Results from this phase of the research effort will be available at the end of FY 82. In addition, an extensive literature review (Walburg et al. 1981a,b) resulted in the collation and synthesis of available information on tailwater ecology. Short-term studies detailing the effects of hydrologic events, describing important biological processes, and developing methodologies to deal with specific tailwater problems are planned for FY 82-83. The following text presents an overview of some of the major findings of this work unit to date.

TABLE 1. RESERVOIR RELEASE STUDY SITES

Location of Reservoir	Project Purpose	River	Type of Tailwater	Length Studied, km
Gillhan Lake, Ark.	N	Cassatot	W	15.3
Pine Creek Lake, Okla.	N	Little	W	12.1
Green River Lake, Ky.	N	Green	C	22.5
Barren River Lake, Ky.	N	Barren	C	20.5
Lake Hartwell Ga.-S.C.	H	Savannah	C	12.5
Beaver Lake, Ark.	H	White	C	5.6
Lake Greeson, Ark.	H	Little Missouri	C	16.1

NOTE: W—Warmwater; C—Coldwater; N—Nonhydropower; H—Hydropower.

IMPACTS OF RESERVOIR RELEASES

Understanding the effects of reservoir releases on the downstream (tailwater) ecosystem and discriminating generalized impacts of impoundments from those associated with specific types of projects requires knowledge of the major biotic and abiotic changes in water as it passes from a stream into a reservoir. In unregulated streams the kinetic energy of flowing water is partially dissipated transporting sediment and bed load. As a consequence, eroded materials washed in from the watershed continuously move downstream from upstream sources. Turbulence within the stream generally prevents stratification; water is continuously mixed and aerated, preventing the production and accumulation of significant quantities of ammonia, hydrogen sulfide, and other reduced substances that require an oxygen-free environment. In addition, scour, abrasion, shifting substrate, and shading by streamside vegetation preclude the proliferation of aquatic vegetation.

When stream water enters the reservoir, wind-driven mixing replaces turbulent mixing. The lack of sufficient turbulence causes most reservoirs to function as particle traps, altering the tailwater substrate and eliminating food sources found in unregulated streams. Reduced sediment concentrations in the discharge, coupled with removal of fine particles by scour below the dam, produces a tailwater streambed composed primarily of coarse cobble and bedrock. Tailwaters downstream from peaking hydropower projects are particularly susceptible to removal of sediments. Increased flow may also result in bank erosion and streambed scour. The biological impact of removing silt and sand is not completely understood although it does produce greater interstitial habitat for benthos.

Leaves, bark, and other detritus of terrestrial origin are important food sources for many aquatic insects in natural streams. This material settles within the reservoir and is only gradually replenished in the tailwater by litter fall from streamside vegetation and tributary input. The abundance of Ephemeroptera (mayflies), an order of aquatic

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insects important as fish food, generally reflects the availability of detritus in the tailwater (Figure 1). Note that the pattern of abundances of Ephemeroptera is the same for all sites even though a variety of project types, sizes, and locations are represented.

The type of food (energy) sources, flow characteristics, and water quality of releases are largely determined by project design and operation. Although most detritus of terrestial origin is lost within the reservoir, it is at least partially replaced in the tailwater by other food sources. Surface-release projects discharge phytoplankton, zooplankton, and fish into the tailwater. The occurrence of large numbers of filter feeding invertebrates downstream from these projects (Ward and Stanford 1979) suggests that this energy source is utilized by tailwater biota. In contrast, deep-release projects discharge clear nutrient-rich water that promotes the luxuriant growth of algae in the tailwater. A variety of benthos are associated with the algae, suggesting that food and cover are being provided for tailwater biota (Pfitzer 1954).

Impoundments can drastically alter the flow characteristics in stream systems. Flood control and irrigation dams generally reduce the magnitude of flood flows by releasing reduced volumes over longer periods of time. Reduction or elimination of floods reduces bank erosion and bed scour and decreases the amount of sediment washed into the tailwater from the flooded bottom lands. The resultant bank and bed stability may enhance the growth of aquatic and terrestial vegetation (Neel 1963). The encroachment of streamside vegetation, which is important in water temperature regulation and shading and in providing food for invertebrates, can further increase bank and floodplain stability. However, such increased vegetative encroachment may result in the eventual loss of part of the water-carrying capacity of the stream by reducing channel size (Maddock 1976). Uniform flows below flood control and irrigation dams often benefit the invertebrate community through the establishment of dense mats of periphytic algae. While these algal mats constitute both a habitat and a food supply for benthic organisms, they may eliminate species adapted to clean rock surfaces (Ward 1976).

Flow fluctuations are more frequent and of greater magnitude below hydropower dams than in natural streams. Large daily flow fluctuations often preclude the establishment of permanent streamside vegetation. The alternate inundation and exposure of the streambed, coupled with extreme

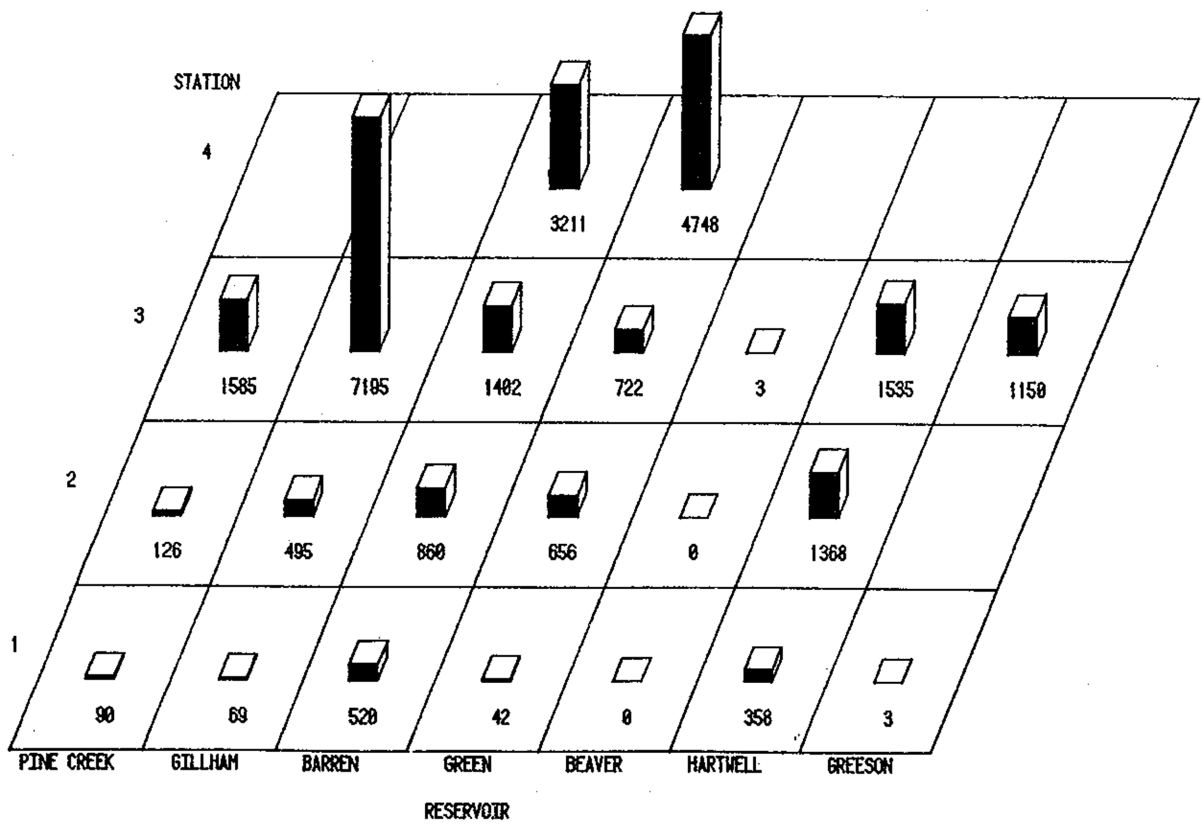

Figure 1. Response of Ephemeroptera (mean number/m^2 over duration of study). Station 1 is the most upstream tailwater station and Station 3 is farthest downstream. Station 4 is upstream from the reservoir inflow. Note that all cases, abundance is greatest at the upstream station if present or at the most downstream station.

variations in flow, may entrain algae, macrophytes, detritus, and benthic invertebrates. Sudden decreases in flow may strand and result in desiccation of attached or immobile species. Overall, the diversity and abundance of tailwater habitat and fish and invertebrate food supply may be significantly reduced by radically fluctuating flows (Neel 1963), although the surge of water from a peaking hydropower plant and the resultant bed scour may indirectly benefit tailwater fish by suspending benthic food organisms thus making them more available (Matter et al. 1981).

The large volume of water in the reservoir is cooled and warmed more slowly than shallow stream water; consequently, natural temperature changes are delayed and temperature fluctuations are dampened in the reservoir (Fraley 1978). These changes can have a severe effect on the tailwater ecosystem since timing of life history stages of aquatic biota is determined to a large extent by seasonal temperature changes. Surface release projects are generally least disruptive to tailwater biota. Stream temperatures are slightly modified and usually within tolerance limits of native biota. However, gas supersaturation can occur in these tailwaters when spillway or turbine releases plunge into deep pools where hydrostatic pressure increases the solubility of the gases. The supersaturated gases come out of solution within the bodies of fish and invertebrates and form bubbles (embolisms) under the skin. This condition is most common in tailwaters downstream from hydropower reservoirs in the Pacific Northwest. Deep releases into coldwater streams generally do not have a severe impact on water temperatures, which usually remain within the tolerance levels of coldwater organisms inhabiting the original stream.

Discharges from deep-release projects subject warmwater biota to a number of stresses that are not generally observed downstream from surface release projects. Reduced water temperatures may fall below the tolerance levels of warmwater species. Altered temperature regimes may disrupt the life cycles of certain aquatic insect species causing them to emerge in the winter or preventing them from hatching in the spring. Reproduction by fish may be inhibited because the cold water disrupts physiological development and eliminates the temperature stimulus to spawn. Figure 2 demonstrates the effects of coldwater releases on abundance of warmwater fish (largemouth bass and channel catfish) as indicated by catch rate. Note the decrease in abundance of these two species of warmwater fish in coldwater tailwaters. However, deep-release projects have produced coldwater (trout) fisheries in the tailwater in areas such as Arkansas and Texas where natural stream temperatures are not cold enough.

Some reservoirs lack sufficient storage capacity of cold hypolimnetic water to maintain coldwater releases throughout the summer and fall. Inadequate

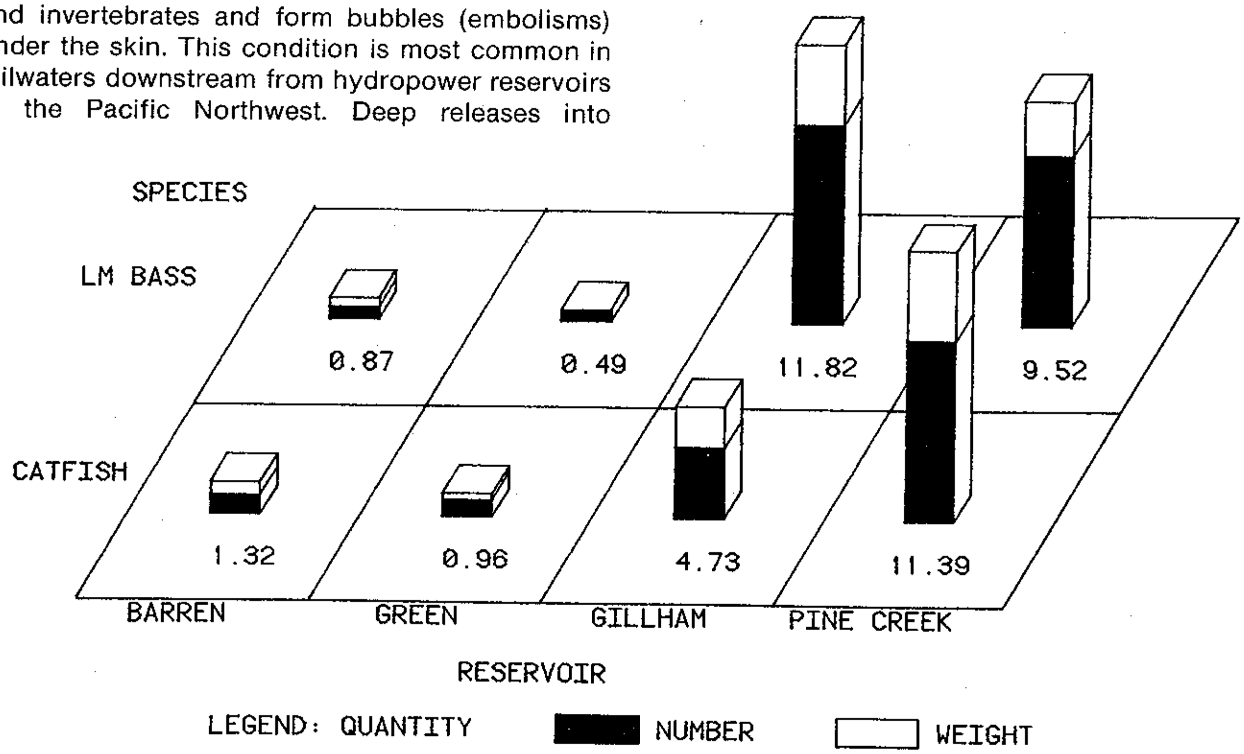

Figure 2. Abundance of channel catfish and largemouth bass in warmwater (Gillham and Pine Creek) and coldwater tailwaters (Barren and Green) as indicated by catch rate (both as numbers and kilograms of fish per hour of electroshocking).

storage capacity may change a coldwater tailwater to a warmwater tailwater during the latter part of the summer. This change significantly affects the tailwater biota because coldwater organisms cannot survive in the warm waters of late summer and warmwater organisms cannot reproduce or grow in the cold waters that occurred earlier in the year. Additionally, severe water temperature fluctuations may occur below dams during periods of low flow or no flow because of atmospheric influence. Such periods are particularly characteristic of hydropower projects where changes in water discharge depend on power demand. Temperature fluctuations of 6-8 degrees C may occur 2 to 3 times a day below these dams (Pfitzer 1968). Water temperatures can approach mean air temperatures if 2 or 3 consecutive days of no flow occurs. The sudden release of large volumes of cold hypolimnetic water during the summer may cause thermal shock. Fish kills have occurred when cold hypolimnetic waters with reduced levels of dissolved oxygen were suddenly released into a tailwater after several days of little or no flow (Krenkel et al. 1979).

The effects of lowered temperature on warmwater tailwaters may be masked by poor water quality in the reservoir releases. During the summer and early fall, deep releases may contain low dissolved oxygen concentrations. Tailwater oxygen levels may be further reduced by the oxidation of iron and manganese present in hypolimnetic releases. Low oxygen concentrations may also intensify the potentially toxic effects of other chemical constituents—including ammonia and hydrogen sulfide.

Reaeration can be rapid, and serious oxygen depletions can be avoided if biological and chemical oxygen demands are not excessive. The rate of reaeration below deep-release reservoirs depends on the design of the outlet works, turbulence of flow in the tailwater, and extent of photosynthesis by aquatic vegetation below the dam. Low oxygen levels may persist farther downstream during peak flow periods, when riffle areas are inundated and more laminar flow conditions exist. In most tailwaters, however, reaeration rapidly increases dissolved oxygen levels as the water proceeds downstream.

The preceding narrative has outlined the major impacts of reservoir releases on the tailwater ecosystem. However, caution must be exercised when applying the results of this or other studies to a specific tailwater. The design and operation of each impoundment reflects various hydraulic, structural, environmental, and economic considerations. As a consequence, each tailwater should be considered a unique habitat warranting at least preliminary investigation before implementation of generalized management practices.

FUTURE STUDIES

Formulation of guidelines that enhance or maintain environmental quality in tailwaters requires information in addition to the long-term effects of reservoir releases. The following studies are planned to provide necessary additional information:

- Assessing the significance of zooplankton export from the reservoir.
- Identifying the rate of recruitment of fishes into the tailwater from the reservoir.
- Describing the effects of water quality changes on stream benthos.
- Developing a new or modifying an existing methodology to determine minimum low flow guidelines for CE reservoir tailwaters.

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REVEGETATION OF RESERVOIR SHORELINES

Charles V. Klimas*

Fluctuating reservoir water levels can result in elimination of shoreline vegetation, producing a broad, unsightly denuded zone. Such bare areas are highly susceptible to erosion and provide little fish and wildlife habitat in comparison with vegetated shorelines. As part of EWQOS Work Unit IIE, studies are under way that are designed to identify plant species and propagation methods that may be used to reestablish shoreline vegetation.

PROBLEM APPROACH

As reported in earlier EWQOS newsletters, three major field sites have been established at Corps reservoirs in Oregon, Texas, and South Dakota. At each site, ponds or subimpoundments were constructed to allow researchers to control water levels, and replicate plantings of selected species were established within the ponds. The Oregon and Texas studies also include replicate plantings directly on the reservoir shoreline where they are subject to uncontrolled water-level fluctuations (Figure 1) and other stresses, such as wave action and ice damage. Two years of field trials have resulted in identification of a variety of plant species that may be successfully introduced into shoreline environments.

Figure 1. Giant reed *(Arundo donax)* at the Lake Texoma shoreline site after 4 weeks of flooding during 1981. Plants are 4- to 6-ft tall.

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RESULTS

Listed below are the common and scientific names of species that have demonstrated good flood tolerance at one or more of the field sites. In some cases, species that performed well at one site proved unsuitable at others (e.g., red-osier dogwood); therefore, the following site-specific discussions are presented.

Woody Species

basket willow	*Salix purpurea nana*
black willow	*Salix nigra*
box elder	*Acer negundo*
cottonwood	*Populus deltoides*
crack willow	*Salix fragilis*
green ash	*Fraxinus pennsylvanica*
lead plant	*Amorpha fruticosa*
persimmon	*Diospyros virginiana*
red-osier dogwood	*Cornus stolonifera*
yellow willow	*Salix lutea*

Herbaceous Species

beaked sedge	*Carex rostrata*
buffalo grass	*Buchloe dactyloides*
cattail	*Typha latifolia*
Columbia sedge	*Carex aperta*
common reed	*Phragmites australis*
duck potato	*Sagittaria latifolia*
giant reed	*Arundo donax*
Lyngby's sedge	*Carex lyngbyei*
prairie cordgrass	*Spartina pectinata*
reed canary-grass	*Phalaris arundinacea*
smartweed	*Polygonum persicaria*
soft-stem bulrush	*Scirpus validus*
spikerush	*Eleocharis ovata*
switchgrass	*Panicum virgatum*
three-square	*Scirpus americanus*
tufted hairgrass	*Deschampsia caespitosa*

Lake Oahe, South Dakota (Missouri River). Seven woody species and 14 herbaceous species were tested at Lake Oahe during the 1980 field season. As in 1979, the most successful woody species was green ash, which showed better than 50-percent survival after 8 weeks of growing-season flooding. Other woody plants that performed satisfactorily include cottonwood, which survived well with 4 weeks of inundation, and yellow willow and box elder, which tolerated 2 weeks of flooding acceptably.

Of the herbaceous plants, five species that

Figure 2. Experimental pond at Lake Wallula during a low-water period, showing replicated plantings in elevational tiers.

performed well in 1979 continued to survive extended flooding in 1980. By far the most successful of these was reed canary-grass, which had very high survival even after 8 weeks of flooding. Other species exhibiting adequate survival in the 8-week zone include common reed, three-square, prairie cordgrass, and cattail. Satisfactory performance with lesser flooding durations (4 weeks) was shown by buffalo grass and switchgrass.

Lake Texoma, Texas-Oklahoma (Red River). Six woody species were introduced to the Lake Texoma experiment in 1980, but these were much less successful than the herbaceous species. Of the woody plants, only lead plant and black willow endured 2 weeks of controlled flooding with greater than 50-percent survival. On the uncontrolled shoreline site, black willow and persimmon persisted after as much as 6 weeks of flooding, but survival was not high (25 to 50 percent).

Of the herbaceous plants, 9 species were remonitored from the 1979 field season and three new species were evaluated in 1980. As in 1979, giant reed was the most flood tolerant of the species tested, surviving very well with 6 weeks of controlled growing-season inundation. Other species performing adequately in the 6-week zone included switchgrass and prairie cordgrass. Buffalo grass survived well with 4 weeks of flooding. On the shoreline site survival was generally lower than in the pond, but giant reed performed adequately with up to 5 weeks of flooding. In the 6-week flood zone, no species was vigorous, but giant reed, switchgrass, and prairie cordgrass persisted to some extent.

Lake Wallula, Oregon-Washington (Columbia River). The Lake Wallula study includes three field sites: (1) a pond where water levels are regulated to produce a daily fluctuation; (2) a mud flat on the reservoir with sporadic exposure to the atmosphere; and (3) a sandy beach on the reservoir where wave erosion is severe.

The pond site contained 8 replicate plantings in 4 tiers; water level fluctuations were controlled such that the highest tier remained dry at all times while the lowest tier was inundated for all but 2 or 3 hours daily (Figure 2). The remaining tiers received intermediate flooding intensities. Of the 10 woody species evaluated, red-osier dogwood and crack willow performed best, showing greater than 50-percent survival in all 4 tiers. Fifteen herbaceous species were tested, and Columbia sedge proved most tolerant of these with at least 50-percent survival in all 4 tiers. Other species that survived well included beaked sedge, tufted hairgrass, and spikerush.

As in 1979, survival on the mud flat was significantly lower than in the pool, probably as a result of winter ice damage and more prolonged periods of flooding. Of the woody species, only red-osier dogwood, crackwillow, and basket willow showed significant survival. One herbaceous species that did not do well in the pond (soft-stem bulrush) was fairly successful on the mud flat. Several species not tested in the pond also performed acceptably on the mud flat, including smartweed, Lyngby's sedge, and duck-potato.

Specialized planting techniques attempted on the beach site in 1980 were largely unsuccessful. However, new approaches taken in 1981 appear to be much more effective, according to preliminary data, and will be described in greater detail in later reports.

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